BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: A Titan-IIIM Launched Space Station Program - Case 710

DATE: July 23, 1968

FROM: E. D. Marion
J. A. Schelke

ABSTRACT

To achieve some understanding of the range of orbital programs available in the post-AAP period, Bellcomm initiated a study to see if a space program could be constructed using a series of small specialist space stations. The experiment requirements from the Saturn V Workshop Study were used to size the small space station modules.

The results showed that a group of small space stations could economically support the maximum experiment package. These spacecraft would be launched on a T-IIIM, and be assembled in space through rendezvous and docking. The crew ascent and return vehicle was the Gemini-B modified to permit aft-end docking. An unmanned logistics vehicle, flying on an Atlas-Centaur class vehicle, proved to be the most economical approach to resupply.

The resulting spacecraft and logistics vehicles could also be used, with only communication system modifications, for military missions.

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(NASA-CR-73576) A TITAN-3M LAUNCHED SPACE STATION PROGRAM. CASE 710 (Bellcomm, Inc.) 31 p

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

A NASA study was recently completed called the Saturn V Workshop Study which was intended to identify potential earth orbital space programs for the 1970 to 1980 period. By direction, one of the programs to be considered was a new-start space station launched in 1971 or 72 with the Saturn V.

The study results said that the spacecraft for this program should be a large multi-disciplinary space station with a six to nine man crew. The study also showed that development of the experiments and of the logistics spacecraft would delay the first flight until the mid 70's. The resulting large station was also incapable of flying a military mission, such as a 100 n.m. polar orbit, even with a small crew.

Because of these shortcomings, it seems worthwhile to seek an alternate space station design concept that would:

1. be less sensitive to the experiment development program,
2. use logistics vehicles with shorter development program,
3. be capable of flying a military mission.

This memorandum presents the results of a study to find such a concept, and also shows the rationale behind many of the decisions. A hypothetical flight program is presented along with some preliminary development schedules and cost estimates. Remember while reading this, that the concept and programs presented here are merely a proof of feasibility and practicality. They are reasonable solutions, not optimum ones. You should also keep in mind that the program is not a stopgap, minimum effort program; it has to meet a complete spectrum of objectives--representative of any long term orbital space program.

2.0 GUIDELINES AND ASSUMPTIONS

The pressure of the three objectives listed above is toward several small space stations, each devoted to a relatively small group of experiments. In the first place, this reduces the sensitivity to the experiment development because the experiments with long lead times can be reserved for later flights, without interfering with the early experiments. In the second place, small stations with small crews need small logistics spacecraft, and this suggests that an existing spacecraft such as Gemini or Apollo may suffice. Finally, a small space station is more compatible with existing payload capabilities for military missions.

2.1 Launch Vehicle

Acting on the idea that the launch vehicle controls the program, the Titan - T-IIIM was chosen as the launch vehicle. The small payload capability of this launch vehicle will keep the spacecraft at a reasonably small size.

However, if during the hardware development the spacecraft becomes too heavy, the launch vehicle can be uprated inexpensively by adding a large diameter core. This idea has already been studied by the Air Force and it gives the program a comfortable safety factor. Another reason for selecting T-III M is that the launch facility for military class missions will already be available.

2.2 Experiments

In the Workshop Study mentioned earlier, three groups of experiments were identified and called the maximum, medium, and minimum packages. The names are indicative of the weight, complexity and development period for the experiment packages. Since the large multi-disciplinary space station could nominally handle the complete maximum package, that was also selected for this study. In some cases, the descriptions of these experiments seems conservative, and in other cases optimistic, still to allow a fair comparison, we decided to use the experiment descriptions and data without question.

In planning the program, biomedical experiments were given highest priority. We assumed that the most important job for the program was to gain experience with long term manned space flight. This experience by itself could not justify a complete program, of course--other experiments must be flown or the program isn't worthwhile. But in case of conflicts, man-in-space experiments would take precedent over other experiments.

2.3 Logistics

Another guideline taken from the Workshop Studies was a resupply interval of 90 days. In many cases, it is not necessary to resupply so frequently, but to make this program consistent with the other workshop programs we assumed a logistics or resupply launch every 90 days, need it or not.

3.0 EXPERIMENT GROUPING

The experiment descriptions are available in full detail in References 1 thru 3. The experiments and associated weights are presented in Figure 1. The weight data from the Workshop Study does not include any structural supports which may be required to connect the experiments to load bearing structure. In some cases where the experiments are mounted inside the space station cabin, no additional support weights are considered because the space station weight estimates include an allowance for support structure. Where an allowance for support structure seemed necessary, it was usually estimated as 50% of the experiment weight. Subsequent evaluation of this approach has shown that it is reasonably valid. The one experiment that was not treated this was the Electromagnetic Radiation (EMR) Experiments. This is a collection of many relatively light sensors. Presumably these sensors can be distributed around the spacecraft structure with little more than simple mounting brackets. It would not be necessary to distribute a concentrated load through support structure. And so, the support weight estimates for the EMR experiment were reduced to about 30%.

The total weight associated with a given experiment is the basic experiment weight plus the support weights.

The experiment groupings have been changed slightly from the Workshop Studies. This was done to separate the man-in-space experiments from the other experiments of a biological nature.

3.1 Experiment Requirements

The orbital characteristics, resupply weights, manpower, and electrical power requirements for each experiment group are shown in Figure 2. These numbers are used throughout the study to insure that any hypothetical collection of experiments is consistant with space station crew size, power system and launch vehicle lifting capability.

FIGURE 1 - EXPERIMENT GROUP WEIGHTS

	EXPERIMENT WEIGHTS Pounds	SUPPORT WEIGHTS Pounds
MAN-IN-SPACE (4000 LB)		
•Imblms	1000	0
•Centrifuge	2000	1000
BIOLOGY (4700 LB)		
•Bioscience/Tech.	2700	0
•Primate	2000	0
ADVANCE TECHNOLOGY (9600 LB)		
•Technology	4100	0
•Life Support	5500	0
EARTH LOOKING (2500 LB)		
•Earth Resources	1670	830
PHYSICAL SCIENCES (14,000 LB)		
•High Energy Physics	14,000	0
ASTRONOMY (18,200 LB)		
•ATM-Solar	3000	1500
•IND Experiments	2000	0
•EMR	6700	2000
•Stellar PKG	2000	1000

FIGURE 2 - EXPERIMENT REQUIREMENTS

EXPERIMENT	MILITARY	MAN-IN SPACE	ASTRONOMY	EARTH LOOKING	BIOLOGY	PHYSICAL SCIENCE	ADVANCED TECHNOLOGY
ALTITUDE, NMI	100	ANY	175-250	125-200	ANY	ANY	ANY
INCLINATION	90°	ANY	0°-30°	60°-90°	ANY	ANY	ANY
ORIENTATION	EARTH	ANY	INERTIAL	EARTH	ANY	ANY	ANY
RESUPPLY WEIGHTS, LB/QTR		150	1070	250	200		50
RESUPPLY INTERVAL, DAYS		90	90	90	90		90
EXPERIMENT WEIGHT, LB	2-10,000	4000	18,200	2500	4700	14,000	9600
MAN HOURS/QUARTER*		1180	1902	672	421	200	400
POWER REQUIREMENTS, WATTS		500	1160	(1000)	3200	(4000)	(500)

* One Man Provides About 780 Man Hours/Quarter

( ) Rough Estimates, Data Not Provided in Workshop Study

Unclassified data on military experiments is understandably scarce. The desirable orbital characteristics were defined, however, by the Air Force during the Workshop Study and are therefore included. Military experiment weights are simply guesses.

4.0 LAUNCH VEHICLE DATA

An important feature of this experiment list is that three experiment groups, military, earth looking, and astronomy have specific and different orbital requirements. This implies that military, earth looking, and astronomy missions should always be on separate flights. Because of security problems, the military mission will probably never have a civilian experiment along with it, anyway. Consequently, the military experiment always flies alone on a military mission. The civilian experiments can share flights, but with the following provisions:

1. man-in-space experiments are on <u>all</u> flights,
2. astronomy and earth looking experiments do not fly on the same flight.

The last provision could be avoided by compromising the experiments slightly and flying a mission with hybrid orbit characteristics. Keeping the high altitude desired by astronomy and the high inclination desired by earth looking gives hybrid mission characteristics of 50° inclination, i, and an altitude, h, of 200 nautical miles.

In the final analysis then, there are four classes of missions which are of interest:

1.	Military	i = 90	h = 100
2.	Astronomy	i = 30	h = 200
3.	Earth Looking	i = 50	h = 125
4.	Hybrid	i = 50	h = 200

The payload capacities of various boosters for each of these mission classes is shown in Figure 3. Payload capacities for the Titan military missions assume a launch from WTR. The same mission with the Saturn family boosters are launched from ETR. The Sat-V numbers assume an overfly of the N. Y. Metropolitan area on the northerly launch, and a Cuban overfly with the first stage

FIGURE 3 - PAYLOAD CAPABILITIES-POUNDS

MISSION CLASS	EARTH LOOKING	ASTRONOMY	MILITARY	HYBRID
ALTITUDE, NMI	125	200	100	200
INCLINATION	50°	28.5°	90°	50°
ORBIT KEEPING, LB/YR*	5100	2700	11,500	3130
SAT-V	235,000	217,000	130,000 (N) 170,000 (S)	207,000
INT-20	124,000	123,000	90,000	116,000
T-3M	36,000	35,500	32,000	33,300
T-3M(LDC)	48,300	51,200	46,000	48,200
T-3G	95,000	97,000	85,000	91,500

* Numbers are for a 15'Diameter Station. For 22' Diameter Propellant Requirements are about double.

impact a few miles from the coast of Cuba on the southerly launch. So treat the quoted payload capacities with caution. Even the INT-20 launch requires a Cuban overfly but the staging is different so first stage impact is not a problem.

Also shown on Figure 3 are the orbit keeping propellant requirements for the various mission classes. The military and earth looking missions are flown with the axis of the space station parallel to the velocity meter (belly-down). The astronomy mission is flown with an quasi-inertial orientation and the axis of the space station in the orbit plane, (axis-in-plane). As the orbit plane precesses, the axis of vehicle will deviate from the orbit plane. Periodic corrections are made to bring the axis back into plane; but between corrections the vehicle is inertially oriented, hence the term quasi-inertial. On the average the vehicle axis is in the orbit plane.

The hybrid mission is flown axis-in-plane 80% of the time and belly-down 20% of the time. The I_{sp} assumed for the orbit keeping propulsion was 340 sec--typical of earth storables. The propulsion requirements do not consider any solar panel drag.

5.0 CREW ROTATION ANALYSIS

The crew rotation analysis is based on the assumption that:

1. the ultimate biomedical goal is to qualify men for inter-planetary flight, by keeping them in orbit for two continuous years.

2. a minimum biomedical sample is two men.

3. after a flight thirty days are required on the ground for a thorough medical analysis.

4. each new flight may be twice as long as the previous one.

5. the AAP program has provided flight durations of about 60 days.

To start off, assume that a six man space station has been launched and manned. Each crew member starts his exposure at the same time. Because of AAP experience, and doubling requirement, each of these men may stay up 120 days. We can't just bring one pair back at the end of 120 days, however, because the others would overstay their allotment while waiting for the 30 day medical analysis. This means the first pair must return at the end of 90 days so that the medical analysis and approval for a longer flight may be completed before the 120 day time limit. Since this first pair has been in orbit for 90 days, the subsequent approval will be for 180 days.

By the same line of reasoning, the second pair must come down 30 days before the 180 days are up, that is after 150 days. And the subsequent approval will be for 300 days.

Each time a pair of crewmen is brought back a fresh pair takes their place. Because of this the final pair from the original crew of six may stay the full 300 days. The other four men with them have not been up anywhere near 300 days when return time arrives, so no allowance for the medical exam time is required.

These rotation requirements are shown in bar chart form on Figure 4.

The program has been extrapolated to a total exposure time for two crewmen of 730 days (2 years). The number at the front of the bar identifies the crewman, and the number at the end shows his total exposure time. The important features of this program, with a single 6 man station, are:

1. 14 astronauts are needed to complete the program.

2. the hardware must be good for 29 months.

3. only 4 crew rotation launches are required over a 2 year period.

If the station were an eight man station, two more horizontal bars could be added at the top of the figure. In essence these two crewmen could stay in the station as long as it was in orbit. The required crew rotations could be made with the other six men. So two years exposure with an eight man space station could be achieved in only 24 months. The only hope for further reductions in the length of the program is to reduce the medical requirements.

Obviously two four man stations launched at the same time are the same as a single eight man station. If, however, one of the two stations is launched a few months later than the other, the total program is lengthened by the difference in the launch date.

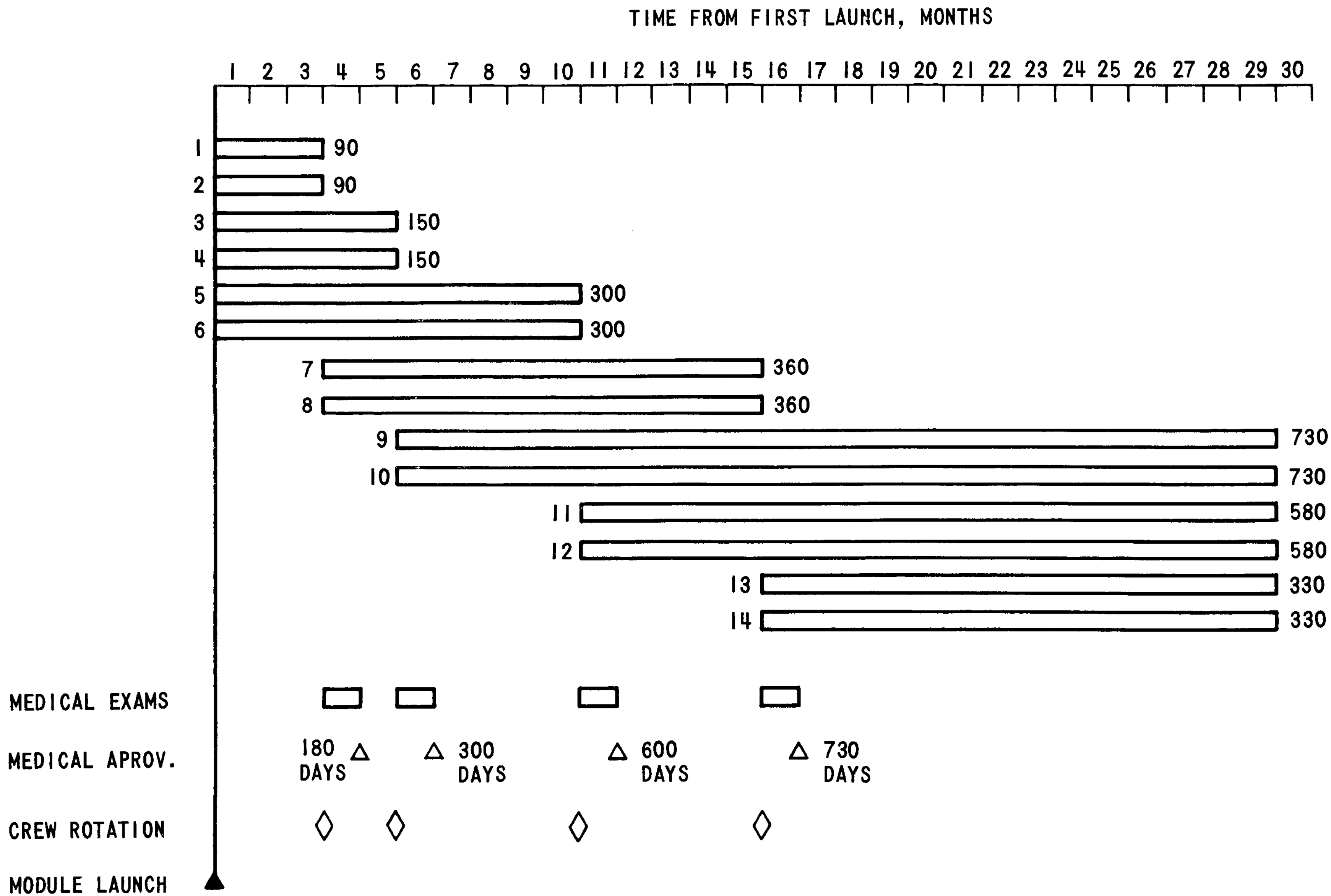


FIGURE 4 - CREW ROTATION REQUIREMENTS
ONE 6 - MAN STATION

The idea of staggered launches turns out to be useful in a different way. Suppose the first four man station was initially launched with only two crewmen on board. The second pair of crewmen could then be brought up about 30 days later. This would mean that the first pair could now stay up for the full 120 days. And after the first medical analysis, the approval would be for 240 days, not the 180 days realized when all the crewmen were launched at once. The net result of all this is that one less crew rotation launch is required. This is shown on Figure 5.

Similar analyses can be conducted for different crew sizes. A summary of the general conclusions is given in Figure 6. The results generally show that if a two year lifetime is imposed on the hardware, then either a large 8 man space station is needed or multiple launches are required.

We might also infer that subsystems should be designed with a 33 month lifetime rather than 24. This would provide some flexibility if it became necessary to juggle the crew rotation schedule later in the program. And it may not be a very difficult job because most subsystems must be maintainable to stay alive for even two years. An extension to 33 months in many cases, would simply mean that more spare parts must be carried along.

This approach to crew rotation analysis is applicable to almost any program planning exercise, but use the results with caution. They may be very sensitive to the initial assumptions. If, for example man had been exposed for 90 or 120 days [illegible] this program then the crew rotation and hardware life- [illegible] ements would change considerably.

[illegible]IPTI[illegible]N

[illegible] program description will obviously constrain the [illegible] for the space station module. It seems reasonable therefore to begin with a description of the program and [illegible]ress to the space station design concepts, launch schedule, development schedule, and costs.

The weights associated with the various experiment groups show that the space station must support, in the worst case, collections of experiments that weigh 14 to 18 thousand pounds. These are the astronomy and physical sciences experiments respectively. These weights coupled with the man-in-space experiment weights, and any reasonable premonition of what the space station and re-entry spacecraft might weigh, lead inevitably to

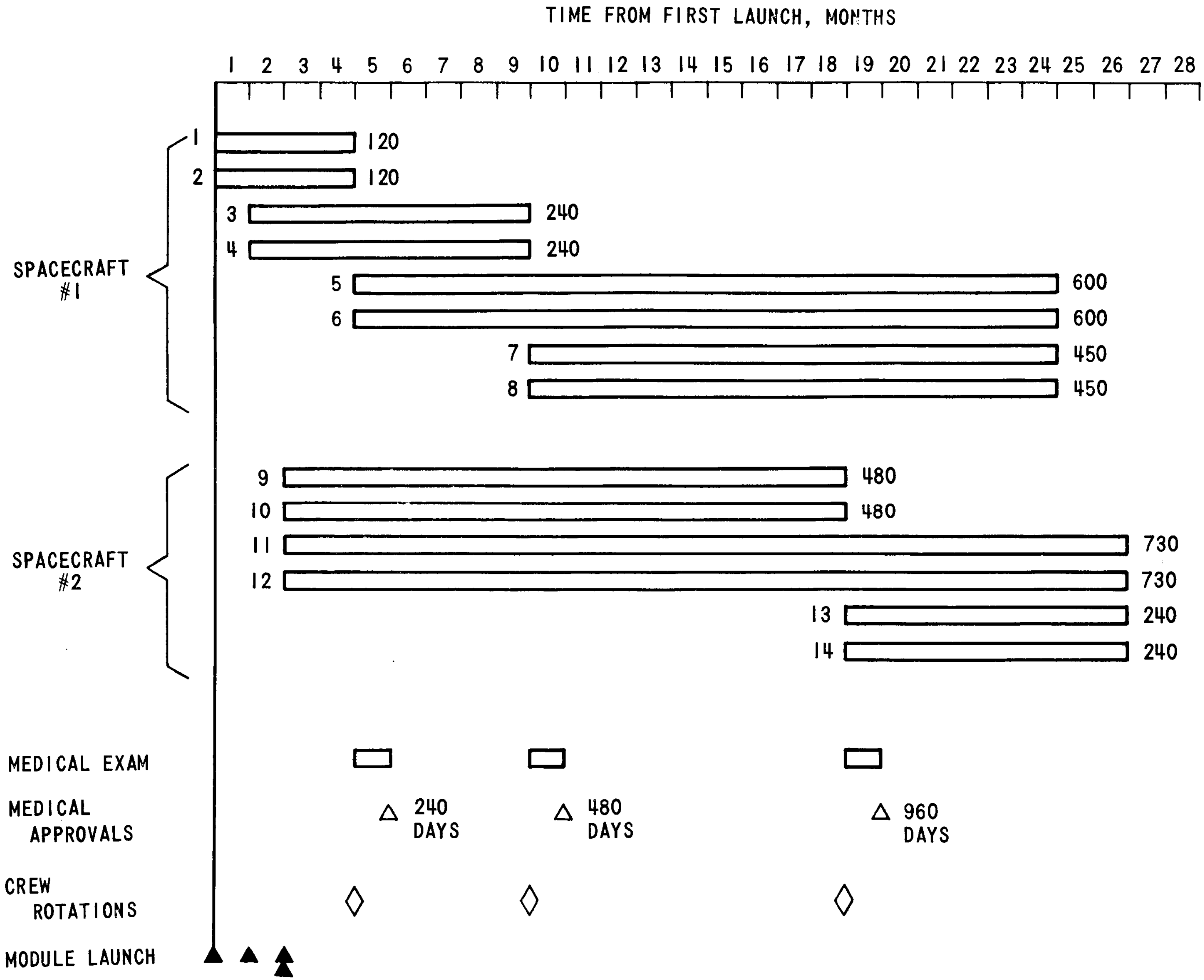


FIGURE 5 - CREW ROTATION REQUIREMENTS
TWO 4 - MAN STATIONS

FIGURE 6 - PROGRAM CHARACTERISTICS

2 YEAR MAN QUALIFICATION

NUMBER OF STATIONS	CREW SIZE	PROGRAM DURATION (MONTHS	STATION DESIGN LIFE (MONTHS)
1	4	33	33
1	6	29	29
1	8	24	24
2*	4	24	24
2**	4	24+x	24

*Simultaneous Launch

**Staggered Launch with X Months Between

Note: If mission is open ended with a centrifuge - both program duration and design life are 24 months regardless of crew size or number of stations.

the conclusion that multiple launches of the T-IIIM will be required. One Titan-IIIM simply could not lift the experiments plus the space station plus the re-entry spacecraft. These heavy experiment groups must be subdivided.

Along the same lines, the crew rotation analysis indicates that two four-man space stations are desirable. But a single four-man space station module is too heavy for the T-IIIM. This coupled with the large experiment weights suggest that 2 two-man space station modules be used. The two modules would each carry part of the experiment load, and would be docked together in space to become a single 4 man station.

This approach will work fine for all the experiment groups except astronomy. It's still too heavy, even when split in two. The approach used here was a separate astronomy module that was launched on a third T-IIIM. Since the astronomy module has no entry vehicle or other experiments associated with it, it is well within the T-IIIM launch capability. And because the other two modules no longer carry part of the astronomy experiment, they can be used to carry some other experiment group.

The resulting program is summarized on Figure 7. The first mission involves 2 launches, one for each two-man module. The second mission is the astronomy mission we've discussed and involves 3 launches--2 for each manned module, and 1 for the unmanned astronomy module. The third mission, like the first, needs 2 launches, but only the first launch is manned. The fourth mission is a single manned launch with only the military experiments on board.

The crew rotation launches are conducted with a Gemini-B modified to allow rendezvous and aft-end docking. The crew is transferred through a tunnel penetrating the heat shield, much the same as the current MOL arrangement. This vehicle is referred to as the manned logistics spacecraft.

6.1 Module Weights

Before defining the weight breakdown for each of the missions, a brief description of the two-man modules is worthwhile. Each module is complete with environmental control, life support, power, and other subsystems required for independent operation with 2 men onboard. To ease orbit keeping propellant requirements, to simplify the attitude control requirements and to reduce the life support power requirements, a 3 kilowatt Brayton-Isotope power system was selected. The power

FIGURE 7 - PROGRAM ELEMENTS

- Gemini-B
- 15' Diameter Module x 17' High
- 2 Men - 2 Years per Module
- Launch Vehicle - T-IIIM
- 4 Basic Missions

(1)	Earth Looking Man-in-Space Biology	60°	125 NMI
(2)	Astronomy Advance Technology Man-in-Space	28°	200 NMI
(3)	Physical Sciences Man-in-Space	28°	200 NMI*
(4)	Military	90°	100 NMI

* Orbital Altitude May be Anything.

requirements for the life support system are reduced by using high temperature waste heat from the Brayton Cycle to desorb the silica gel and molecular sieve beds. Using this approach, the two man life support system can operate on about 1 kw. If two space station modules are used, only spare parts are needed for the power system, because one module can borrow power from the other if a breakdown occurs. If a module is flying alone, redundant elements must be added to the power system to provide power while repairing the failure. Power system weights for a 5 kw Brayton/Isotope system, and the 3 kw system weights which were derived from them are shown in Figure 8.

The ECLSS is a closed system with Sabatier oxygen recovery, and air evaporation for urine water recovery. Expendables are stored non-cryogenically; nitrogen as ammonia and oxygen as water. This system is discussed in detail in Reference 4.

The module itself is about 17 feet long and 15 feet in diameter, with flat bulkheads. The 17 foot length includes a 3 foot long unpressurized section which contains the expendables storage tanks and the electrical power system.

Weight estimates for the module are given in Figure 9. In evolving the program, we found a need for three kinds of modules:

1. A module, called a control cabin, which contains the communications and data management center, the guidance and control computers and other gear association with monitoring the status of the mission. These equipments are lumped under the heading "mission equipment" in the weight breakdown. All space stations must have at least one of these modules.

2. A module, called an experiment cabin, which is identical to the control cabin except that it contains no mission equipment. Both the control and experiment cabins have all the facilities to support 2 crewmen. The experiment cabin has a slightly lighter water and waste management system because it contains no zero-g shower.

3. A module, called the experiment shell, which provides only a pressurized volume. Since the crew may work in this module, atmosphere and environmental control must be provided. Some water management must be included to handle metabolic water condensed from the atmosphere. And since, with a closed life support system, consumables are primarily for leaks, this module must carry

FIGURE 8 - ESTIMATED POWER SYSTEM WEIGHTS

	5KWT		3KWT	
	SINGLE MODULE	MULTIPLE MODULE	SINGLE MODULE	MULTIPLE MODULE
FUEL BLOCK	800	800	480	480
RE-ENTRY PROTECTION	350	350	240	240
STRUCTURE	100	100	75	75
RECOVERY AIDS	70	70	70	70
ABORT ROCKETS	130	130	110	110
TOTAL LHS/IRV	1450	1450	975	975
PCU PACKAGE	950	950	800	800
REDUNDANT COMPONENTS	300	0	280	0
SPARE PARTS	250	250	150	150
SHIELD	600	600	200	200
TOTAL	3550	3250	2405	2125

FIGURE 9 - MODULE WEIGHTS

	CONTROL CABIN	EXPERIMENT CABIN	EXPERIMENT SHELL
FOOD	2500	2500	0
ATMOSPHERE	3800	3800	3800
THERMAL CONT.	300	300	300
CREW SYSTEM	1000	1000	0
WATER AND WASTE	700	600	100
MISSION EQUIP.	2000	0	0
POWER (3KW)	2200	2200	0
BASIC STRUCTURE	5600	5600	5600
SUPPORT STRUCTURE	1500	1500	1500
INTERSTAGE	800	800	800
CMG's	800	0	0
MODULE WEIGHT	21,200	18,300	12,100

Module Dimensions are 15' Dia. x 17' tall. This provides living quarters and room for experiments.

a full load of atmoshpere consumables. The weight breakdown shows the experiment shell without a power system, although this could be added.

These three module types are simple derivatives of the common mission module concept. The basic module design is the control cabin, and the other modules are achieved by simply not installing various components or subsystems. We can view this as stopping the assembly process at certain points on the assembly line, and using the partially completed vehicle. A spacecraft design concept is shown in Figure 10. These sketches were excerpted from a related but separated design study so the design details may not be completely appropriate. The concepts are presented here to show that the size selected has some support from more detailed studies, and should provide ample room for the necessary experiments and a two man crew.

A typical module as it might look mounted on the T-IIIM is shown in Figure 11. Hammerheading is required, but this seems to be well within the limits defined in Reference 5, by the Martin Co.

6.2 Mission Descriptions

The missions described below are launched with 6 months worth of orbit keeping propellant. This is safe in light of the 90 day resupply interval, but in actual fact, the orbit keeping propellants would be loaded to the limit of the booster capability.

Mission one is a two launch mission, which handles the earth looking, biology, and man-in-space experiments. Both launches are manned, and rendezvous and docking is used to assemble a single four man space station. The launches are considered simultaneous, however, the first module launched is the control cabin, complete with orbit keeping propulsion. If a delay in the second launch occurs, the first module up can maintain itself until the second module arrives. The weight breakdown for this mission is shown in Figure 12.

Someone is bound to notice that this space station does not have redundant entry vehicles, so a word about that and the associated safety problem is in order. To begin with, safety considerations say that no single failure should destroy the crew's access to an entry vehicle--so let's examine the existing design to see if this is violated.

If a vital or catastrophic failure occurs in the space station, the entry module, with its completely separate systems,

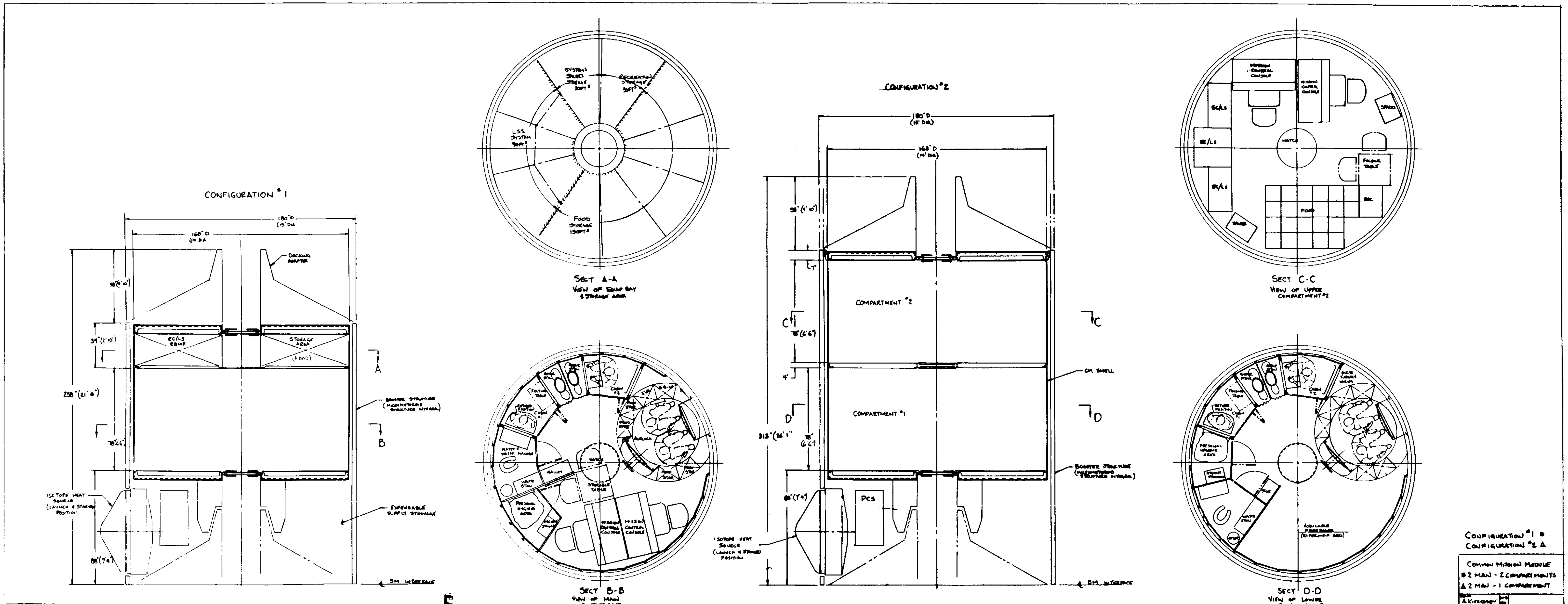


FIGURE 10 TYPICAL CONFIGURATION CONCEPTS

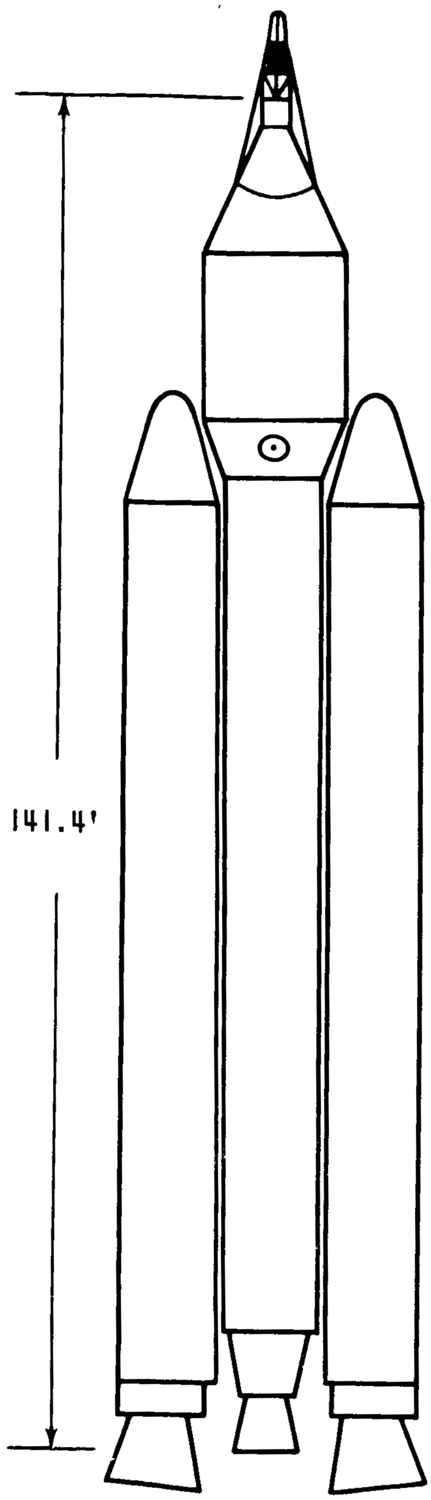


FIGURE 11 - T-IIIM LAUNCH CONFIGURATION

FIGURE 12 - MISSION 1

Earth Looking, Man-In-Space, Biology

	LAUNCH 1	LAUNCH 2
MODULE WEIGHT	21,200	18,300
PROPULSION	2,600	0
LOGISTICS(GEMINI)	6,800	6,800
EXPERIMENTS		
EARTH LOOKING	2,500	
MAN-IN-SPACE		4,000
BIOLOGY		4,700
LAUNCHED WEIGHT	33,100	33,800
PAYLOAD MARGIN	2,900	2,200
	36,000	36,000

MAN-HOURS/QTR, required	2,273 (experiments only)
MAN-HOURS/QTR, supplied	3,120 (total)
MAXIMUM POWER REQUIRED (expts)	4,700 watts (everything on)
POWER SUPPLIED (expts)	3,000 watts (continuous)

should still be operable and the crew could get to it either through the transfer tunnel or through EVA. If something has happened to the entry vehicle, the crew can simply stay in the space station until a new unmanned entry vehicle can be supplied from earth. This means that the space station must have a design life longer than the program life to cover the unlikely event that the entry vehicle fails right at the end of the program.

The crew is vulnerable to a station failure while waiting for the arrival of a new entry vehicle, but this is really a problem of double failures--entry vehicle plus space station.

Beyond that, there is even some confusion about what the safety problem is. Airline passengers, light plane pilots, and fighter pilots do not carry defense against abnormal operaation. (For a fighter pilot to be shot down is not abnormal, therefore, his chute is simply an alternate mode of operating. He does not carry a second chute as protection against abnormal chute operation.)

Although the safety requirements need better definition,in the final analysis, redundant entry vehicles did not seem necessary so they are not considered here. If they must be included, then a separate launch using the Gemini launch vehicle may be required. Suffice it to say that there are solutions to the safety problem, regardless of its utilmate disposition.

Mission two is basically the astronomy mission, but also includes man-in-space, and advanced technology. The first launch is a control cabin containing the technology part of the advanced technology experiment. The second launch is an experiment cabin containing the life-support part of the advanced technology experiment, plus the man-in-space experiments. The final launch is an unmanned astronomy module. The weight allowance for the module is the weight of an experiment shell, although some preliminary analyses indicate that this number may be too high. In any case, another launch would still be needed, although a smaller weight for the module might mean a cheaper launch vehicle. The mission two weight breakdown is given in Figure 13.

The orbital assembly operations are shown schematically in Figure 14. The two manned modules are launched first and are docked base-to-base. The Gemini spacecraft on one end is then manned, flown around and docked to one of the docking ports on the side of the cabin. The adapter section which connected the Gemini to the station module during launch is then jetisoned, exposing the main docking structure. The astronomy module is

FIGURE 13 - MISSION 2

Astronomy, Man-In-Space, Advance Technology

	LAUNCH 1	LAUNCH 2	LAUNCH 3
MODULE WEIGHT	21,200	18,300	12,100
PROPULSION	1,300	0	0
LOGISTICS	6,800	6,800	0
EXPERIMENTS			
TECHNOLOGY	4,100		
LIFE SUPPORT		5,500	
ASTRONOMY			18,200
MAN-IN-SPACE		4,000	
LAUNCHED WEIGHT	33,400	34,600	30,300
PAYLOAD MARGIN	2,100	900	5,200
	35,500	35,500	35,500

MAN-HOURS/QTR, required	3,482 (experiments only)
MAN-HOURS/QTR, supplied*	3,120 (total working hours)
MAXIMUM POWER REQUIRED (expts)	2,160 watts (everything on)
POWER SUPPLIED (expts)	3,000 watts (continuous)

* Requires reduced accomplishment rate or more automation.

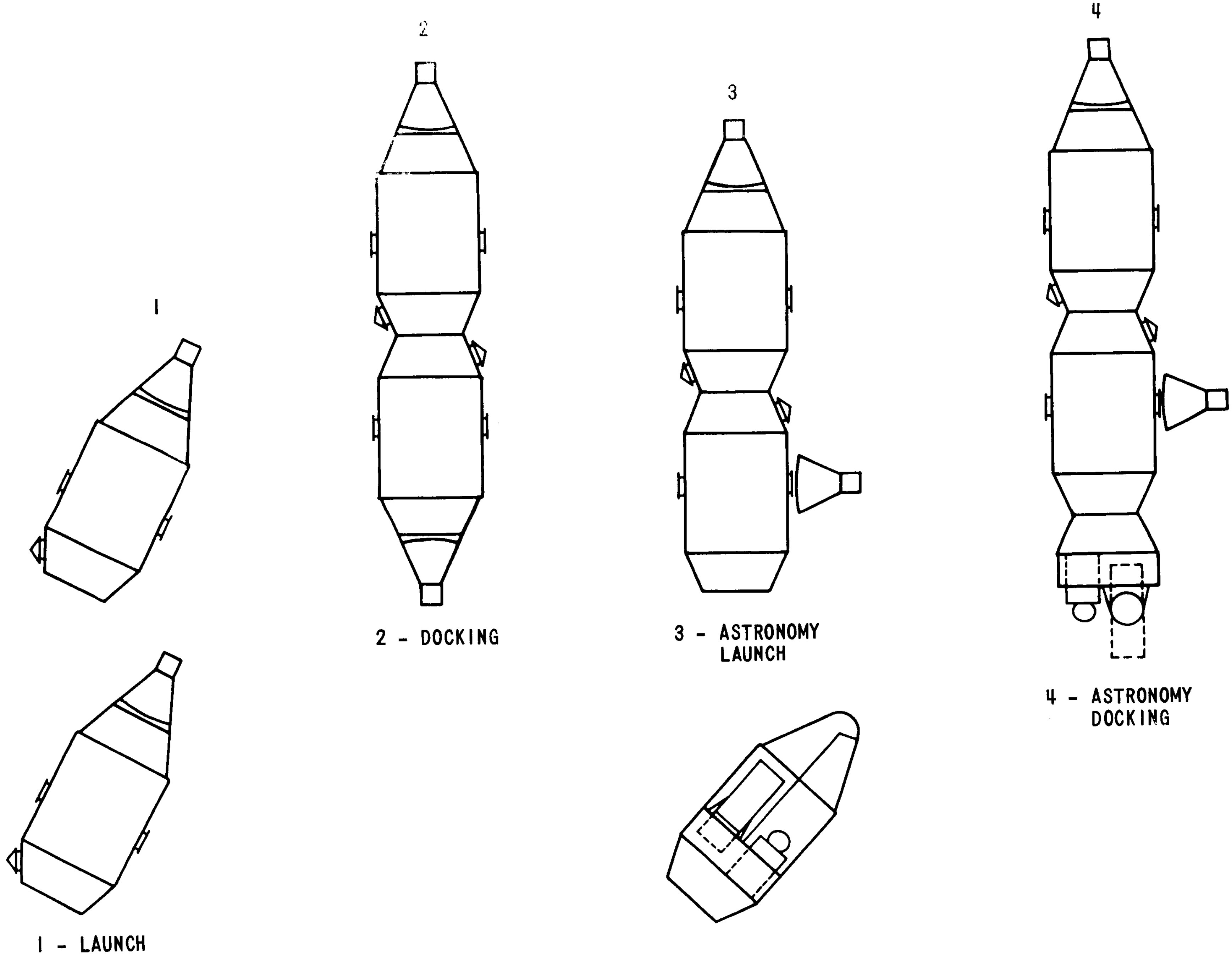


FIGURE 14 - ORBITAL ASSEMBLY

then launched and rendezvoused with the assembled station. Docking is performed with the astronomy module as the passive element and the station, guided by the astronauts, as the active element.

Mission three conducts the physical sciences and the man-in-space experiments. The first launch is a control cabin containing the man-in-space experiments. This is not absolutely necessary since the first two missions provide two four-man space stations, and this is enough to gather all the desired man-in-space data. Still one ground rule was that all NASA missions would include the man-in-space experiments, so they are included here. The second launch is an unmanned experiment shell containing the physical sciences experiment. It also has a power supply added to the experiment shell because the physical sciences experiments promise to consume large amounts of power. The resulting station is a two-man station and is consistent with the man-hour estimates for the physical sciences experiments. A weight breakdown is given in Figure 15.

The fourth mission is the military mission, and, by edict, must involve only one launch. High orbit-keeping propellant requirements, coupled with the low payload capacity for the military orbit, make it impossible to carry a significant amount of experiments along with the normal expandables load. Consequently all expendables,--atmosphere, food and propellants,--are reduced to match some initial small mission duration. Subsequent resupply can extend the mission duration as far as required. A detailed weight breakdown for a 4 month and a 2 month initial duration are given in Figure 16.

The NASA missions can be combined into a complete program, using the crew rotation analysis described earlier. This is shown in Figure 17. The military program is not shown since it is a separate program from a different launch facility. The launch facility for the NASA program has two pads with a turnaround time of 30 to 60 days.

6.3 Logistics

A quick count shows that there are 19 logistics launches in this program. There would be more but, some of the crew rotation launches can do double duty. The weight requirements for the logistic launches is shown in Figure 18.

There are two important features of the logistics requirements. First the weights are all quite small--the largest is less than 4,000 lbs. Second the largest experiment support weight is about 1,300 lbs, while the largest propellant requirement is about 2,900 lbs. In other words, one unmanned logistics

FIGURE 15 - MISSION 3

Physical Sciences, Man-In-Space

	LAUNCH 1	LAUNCH 2
MODULE WEIGHTS	21,200	14,300
PROPULSION	1,300	0
LOGISTICS	6,800	0
EXPERIMENTS		
PHYSICAL SCIENCES		14,000
MAN-IN-SPACE	4,000	
LAUNCHED WEIGHT	33,300	28,300
PAYLOAD MARGIN	2,200	7,200
	35,500	35,500

MAN-HOURS/QTR required	1,380 (experiments only)
MAN-HOURS/QTR supplied	∿ 1,500 (total working time)
MAXIMUM POWER REQUIRED (expts)	∿ 4,500 watts (everything on)
POWER SUPPLIED (expts)	∿ 3,000 watts (continuous)

FIGURE 16 - MISSION 4

Military

	4 MONTHS	2 MONTHS
FOOD	420	210
ATMOSPHERE	1390	1150
THERMAL CONTROL	300	300
CREW SYSTEM	1000	1000
WATER AND WASTE	700	700
MISSION EQUIPMENT	2000	2000
POWER (3KW)	2400	2400
BASIC STRUCTURE	5600	5600
SUPPORT STRUCTURE	1500	1500
INTERSTAGE	800	800
CMG's	800	800
MODULE WEIGHT	16,910	16,460
PROPULSION	3,900	1,950
LOGISTICS	6,800	6,800
EXPERIMENTS	3,000	5,000
LAUNCHED WEIGHT	30,610	30,210
PAYLOAD MARGIN	1,390	1,790
	32,000	32,000

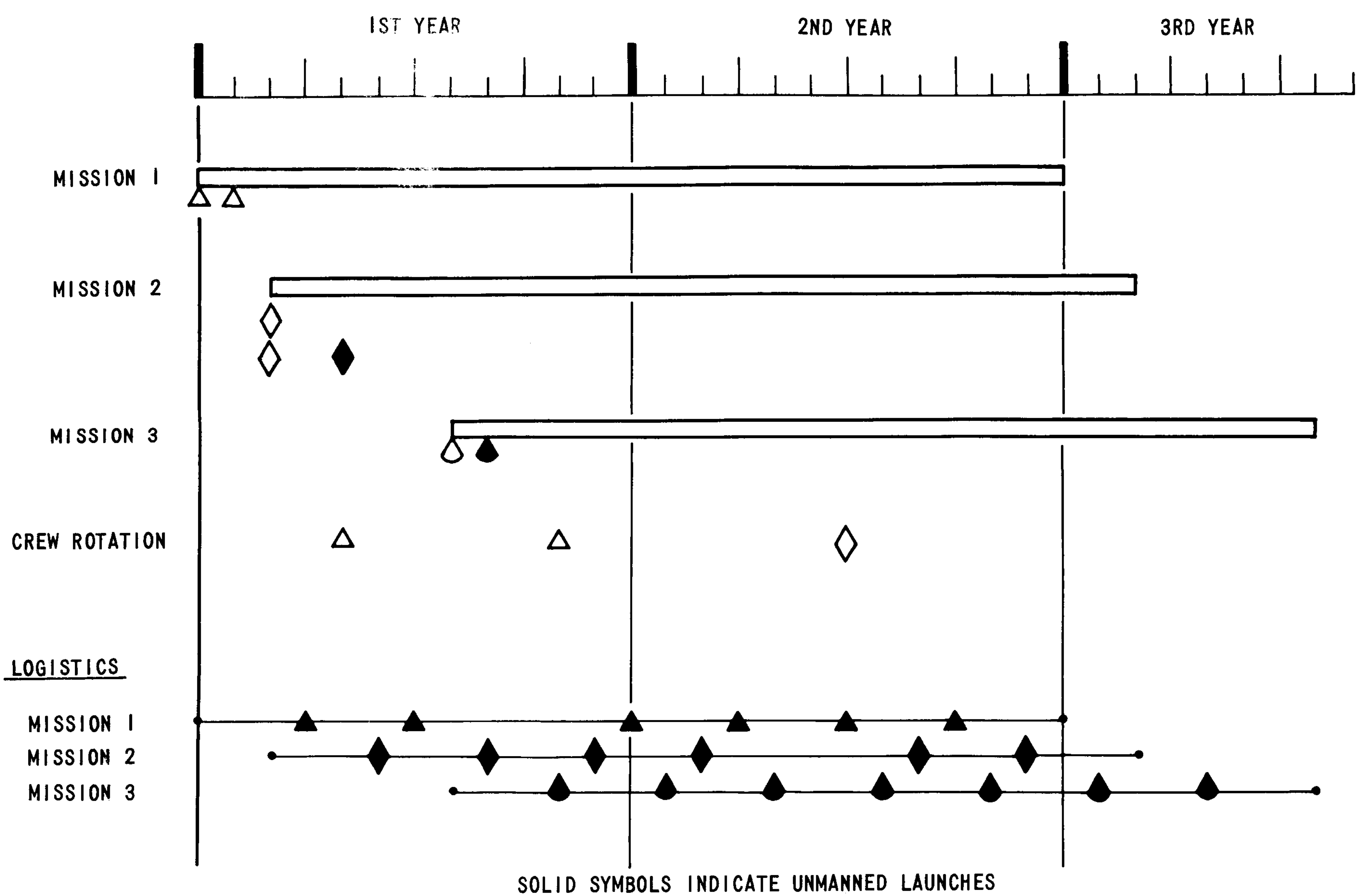


FIGURE 17 - NOMINAL PROGRAM LAUNCH SCHEDULE

FIGURE 18 - LOGISTICS WEIGHTS

	LB/QUARTER
MISSION 1	
EARTH LOOKING	250
MAN-IN-SPACE	150
BIOLOGY	200
	600
PROPELLANT	1275
TOTAL	1875 LB/QUARTER
MISSION 2	
ADVANCE TECHNOLOGY	50
ASTRONOMY	1070
MAN-IN-SPACE	150
	1270
PROPELLANT	675
TOTAL	1945 LB/QUARTER
MISSION 3	
PHYSICAL SCIENCES	0
MAN-IN-SPACE	150
	150
PROPELLANT	675
TOTAL	825 LB/QUARTER
MISSION 4	
MILITARY	500?
PROPELLANT	2875
TOTAL	3375 LB/QUARTER

vehicle, capable of supplying about 1,300 lbs of experiment equipment (such as film) and 2,900 lbs of earth storable propellants would suffice for all missions.

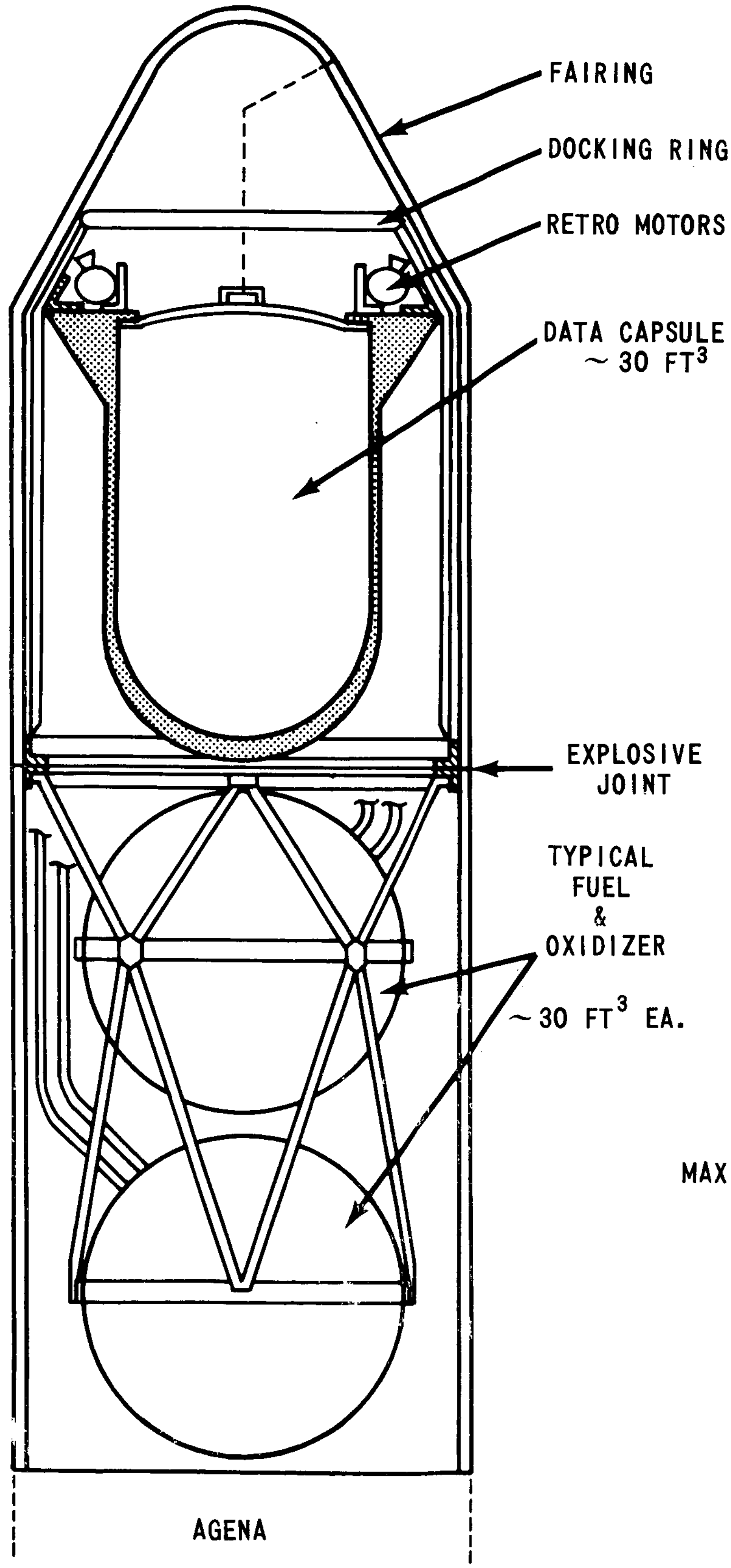
Following this line of reasoning a little farther notice that the total logistics craft weights would fall in the 5,000 to 7,000 lbs range. This is just about the lifting capacity of the standard Atlas Agena. Since the Agena is 5 feet in diameter a 5 foot unmanned logistics vehicle seems like a reasonable approach. A hypothetical design for such a vehicle is shown in Figure 19.

The design includes a data return capsule which is packed with experiment supplies before launch. The crew removes the supplies, repacks the data dapsule with experiment data and materials, and jettisons the data capsule.

A typical sequence of logistics operations is shown in Figure 20. The capsule performs a rendezvous with the spacecraft and docks at one of the docking ports on the side of the module. The rendezvous capability is included in the Agena vehicle, although the maneuver is controlled from the manned station. A large pressurizable transfer tube connects the cargo compartment to the space station cabin. Umbilical connections to the logistics vehicle fuel tanks can be made in several ways. The docking operation itself could join two quick disconnect fittings outside the transfer tube or fittings inside the tube could be connected manually by the crew.

The first operation is to transfer propellants. When this is completed, the propellant tank is severed and the Agena backs away, carrying the propellant tanks and some of the docking structure with it. The cargo is then unpacked and the cpasule reloaded with data. The space station is then oriented for proper ejection of the re-entry capsule. The entry capsule itslef contains a small two axis gyro system that is then spun up using station power. These run on momentum when disconnected from the station and will provide about 20 minutes of inertial reference for the entry body. A small entry computer and a cold gas attitude control system will then orient the data capsule for the de-orbit thrust which is delivered by a small solid rocket motor. The data capsule is designed to be aerodynamically stable, however, the attitude control system can provide control during the early stages of re-entry.

Most of the remaining logistics docking structure enters with the data capsule. Any structure left behind is either drawn into the spacecraft and stowed, or is jettisoned and allowed to re-enter. To hasten decay the jettisoned structure may be covered with a thin sheet of mylar.



WEIGHT ESTIMATES, LB.	
TANKS	300
STRUCTURE	400
PLUMBING	50
G & N	50
RETRO PROP	100
RE-ENTRY VEH.	1000
FAIRING	700
TOTAL	2600 LB.

MAXIMUM WEIGHT, FULLY LOADED
~ 6900 LB

FIGURE 19 - UNMANNED LOGISTICS VEHICLE

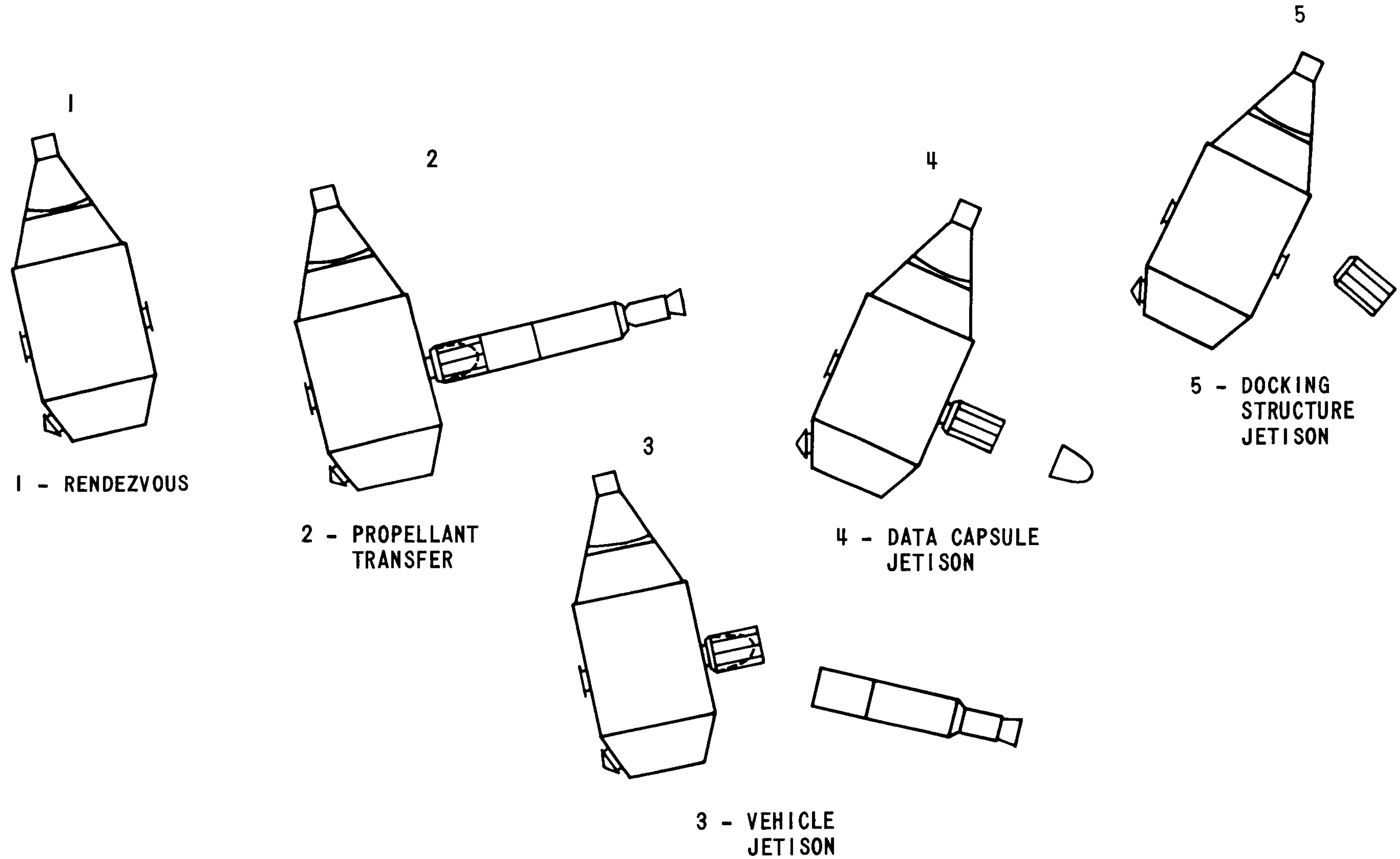


FIGURE 20 - LOGISTICS OPERATIONS

The logistics vehicle design has not been pursued beyond the conceptual stage, so many of the design details are undefined. But the results so far show that an adequate unmanned logistics vehicle, of the kind described here, is technically feasible and would be small enough to use a launch vehicle of the Atlas-Agena or Atlas-Centaur class.

7.0 COST AND PROGRAM SCHEDULE

Program costs and scheduling is based upon the assumption that the new spacecraft modules would be similar, in terms of time and dollars, to the "C" workshop option evaluated in the Saturn V workshop study. We also assumed that the integration and test philosophy for the experiment packages would be similar.

Although one of the original ideas was to permit an early first launch by grouping the experiments appropriately, it turned out that one of the limiting experiments was the advanced IMBLMS which goes on every mission. So the desired schedule savings couldn't be realized.

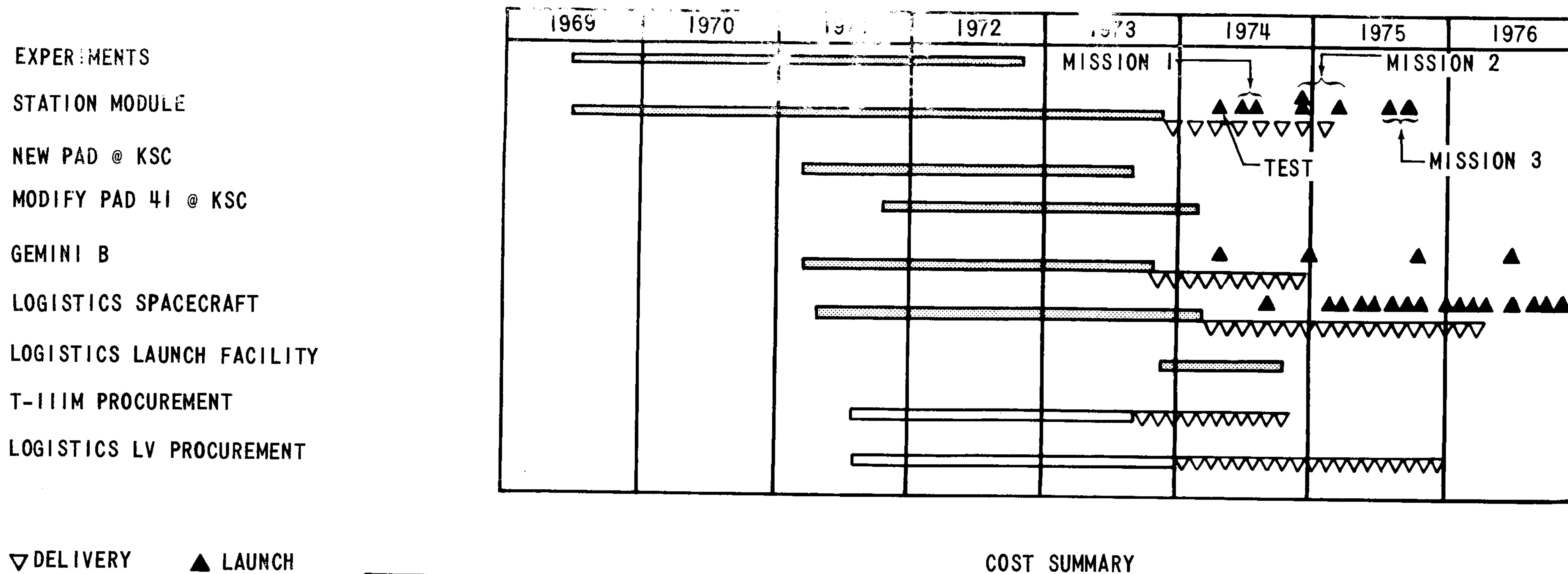
As a consequence, the experiment grouping shown is simply organized by technology. The program could be accelerated about 6 months by accepting an intermediate IMBLMS design, however, this would require re-grouping the experiments to get the primate experiment (another long-lead experiment) off of the first launch. The program shown has a first launch in mid '74, the same as the workshop study.

Analysis showed that Titan III vehicles and launch facilities could be easily provided within this time, and so were scheduled to begin as late as possible to reduce early expenditure rates.

A new launch facility at ETR and modification of existing pad 41 would be required to support the dual launches necessary to the program.

Since docking capability is required from the Gemini-B, the program includes an allowance for development and flight testing of the modified Gemini-B spacecraft.

The program also includes development of the unmanned logistics spacecraft, for use on an Atlas-Agena class launch vehicle.



COST SUMMARY

	TOTAL	1969	1970	1971	1972	1973	1974	1975	1976
EXPERIMENT	699	29	84	190	245	131	20		
STATION MODULE	1003		42	132	273	396	160		
T-IIIM LAUNCH FACIL. (NEW)	46			7	26	13			
T-IIIM LAUNCH FACIL. MOD. 41	15			1	9	5			
GEMINI B DEV & FLT TEST	203			64	87	52			
GEMINI B & LV PROCUREMENT	162				43	81	36	2	
T-IIIM PROCUREMENT	140			10	81	47	2		
LOGISTICS S/C DEV	45			15	18	10	2		
LOGISTICS S/C & LV PROC. & LAUNCH	198				5	20	50	75	48
TITAN IIIM LAUNCH	48						40	8	
	(2770)								
TOTAL BY YEAR		29	126	419	787	755	310	85	48
CUMULATIVE BY YEAR			155	574	1361	2116	2426	2511	2559

FIGURE 21 - PROGRAM COSTS AND SCHEDULE

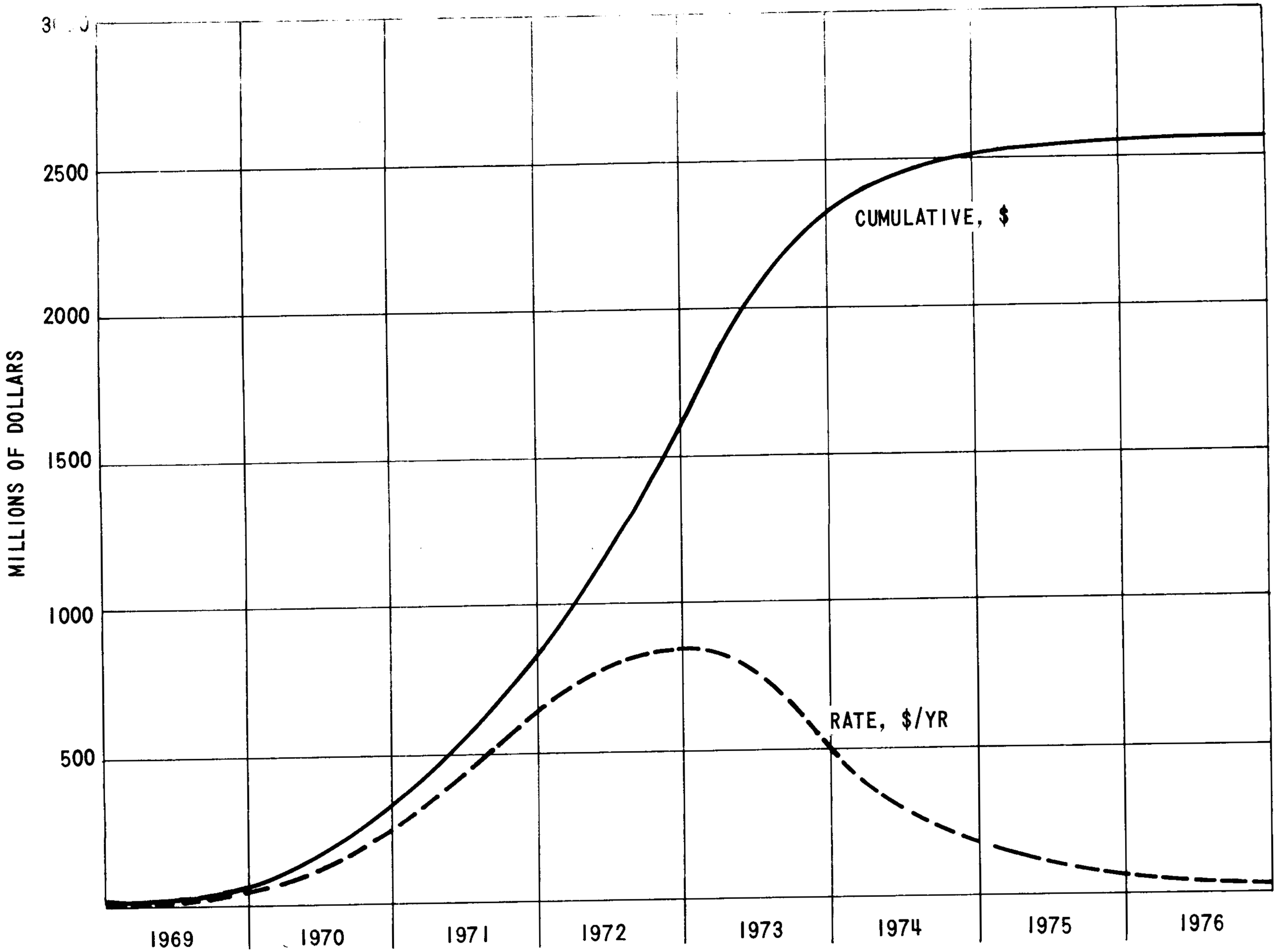


FIGURE 22 - PROGRAM COST SUMMARY

7.1 ANALYSIS

The cost and schedule data for the experiments were taken without change from the Saturn V workshop study. Module development costs were estimated at 600 x 10^6\$ with a 50 x 10^6\$ unit cost. This was estimated based on MORL, EOSS and BSM study results (References 6, 7, and 8). The costs were time-distributed in proportion to the workshop study results.

Cost of a dual launch facility for the T-IIIM at ETR was taken as the total of a Martin Company estimate for a new pad, plus the OWS study estimate of modifying pad 41 for NASA use. The same pad is used for manned logistics spacecraft launches.

Cost and procurement time estimates for launch vehicle and Gemini-B spacecraft were provided by the respective manufacturers.

In each case, total cost figures obtained were allocated over the required development time in accordance with a standard cost accumulation curve as a means for establishing yearly costs.

The program costs and schedule are shown in Figure 21. The cost data is plotted to show yearly and cumulative spending in Figure 22.

8.0 CONCLUSIONS

The primary conclusion from this study is that an extensive earth orbital program can effectively be supported by the T-IIIM launch vehicle. Detailed analysis of the spending rates and total program costs show that total program cost and peak spending rates are about the same for both the Saturn V launched spacecraft and for the small modular station. The important difference is that the small modular station, with experiments distributed over multiple launches, can respond to changes in funding by postponing the development of experiments, while continuing the development of the spacecraft. In addition, the station orbit can be more responsive to individual experiment requirements.

The use of the T-IIIM is also desirable because of the ready adaption to the military mission. This might permit some financial cooperation between the Air Force and NASA. In addition, the potential uprating of the T-IIIM by adding a large diameter core has been well studied, and offers both program growth potential and insurance against the need for drastic launch vehicle changes to accomodate unavoidable weight growth.

As a general conclusion, the use of a small modular space station, launched on a T-IIIM is an attractive approach from the technical, scientific, and programmatic viewpoints.

E. D. Marion

1012-$\frac{\text{EDM}}{\text{JAS}}$-pap

J. A. Schelke

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